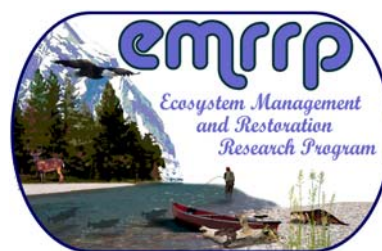


Live Stake and Joint Planting for Streambank Erosion Control



by Robbin B. Sotir and J. Craig Fischenich

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Complexity	Environmental Value	Cost
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Low Moderate High	Low Moderate High	Low Moderate High

OVERVIEW

The live stake (LS) and joint planting (JP) soil bioengineering systems are units fabricated from live, woody plant material branches. Over time, the LS's are effective for erosion control and the JP system provides reinforcement to slopes upon which rock has been placed. The LS and JP live cut branches are expected to grow roots and top growth, with the roots providing additional soil reinforcement and surface cover providing protection from runoff and streamflow. The LS and JP units are used from the baseflow elevation up the face of the streambank, acting principally to protect the bank toe and face. In the case of the JP's, the root soil reinforcement serves to augment bank protection. The LS's and JP's are also useful to improve erosion control and infiltration and support the riparian zone. Once top growth has developed, both systems have the potential to accumulate sediment (Figures 1-7).



Figure 1. Fabricating a live stake or joint planting unit



Figure 2. Installing a live stake



Figure 3. Installing a joint planting

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Figure 4. An establishing live stake area



Figure 5. An establishing joint planting area

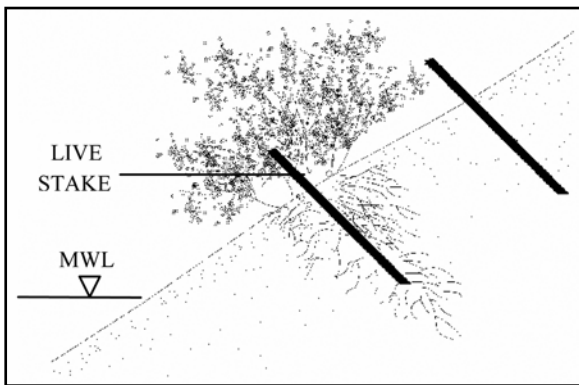


Figure 6. Development of a live stake installation

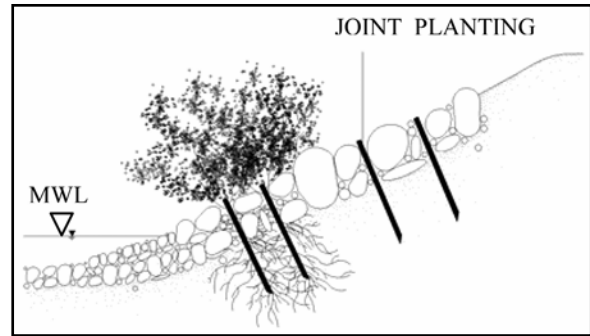


Figure 7. Illustration of the development of a joint planting installation

The LS and JP may improve aquatic habitat by providing food and cover in the riparian zone and over the water when they are used in close proximity to the edge of the stream. Stone used at the base of the LS or with JP produces substrates suited for an array of aquatic organisms. Some of these organisms adapt to living on and within the rocks and some attach to the leaves and stems. The leaves and stems may also become food for shredders.

Species for LS and JP systems can be selected to provide color, texture, and other attributes that add a pleasant, natural landscape appearance. Such plants for LS and JP systems include willow (*Salix* spp.), which tends to be the best from an adventitious rooting perspective and is normally an excellent choice. However other species such as poplar (*Populus* spp.), *Viburnum* spp., *Hibiscus* spp., shrub dogwood (*Cornus* spp.) and buttonbush (*Cephalanthus*), also work well. After establishment, the LS and JP systems can reduce non-point pollution by intercepting sediment and attached pollutants that otherwise enter the stream from overbank flow areas.

PLANNING

The first step in the planning process is to determine whether an LS or JP system is an appropriate alternative to address the observed and projected mechanisms of bank loss. Questions that must be addressed include the following inter-related items (not exhaustive):

1. Is an LS or JP system an appropriate alternative given the magnitude of the erosion problem, e.g. its geomorphic and morphological characteristics?
2. Will the hydrology of the stream accommodate an LS or JP system that produces woody growth?
3. Are stream velocities and shear stresses permissible, and is the risk of ice and debris damage acceptable?
4. Will sediment accumulation be a positive or negative result for plant establishment and survival?
5. Will there be enough sunlight and water to support the desired system?
6. Are there riparian woody plants in a reference reach or nearby similar system that can be used as a template (and perhaps material source) for the construction of an LS or JP system?
7. Will site conditions during construction permit installation?
8. Have risks, and specifically the consequences of failure, been considered and what are they (e.g., what happens if the LS or JP system becomes dislodged and materials move downstream)?
9. What other erosion control devices or materials will be needed, such as grade control in the bed, a filter fabric or stone in the JP or an erosion control fabric (ECF) on the bank?
10. Is the required construction season available?
11. Is depredation a potential problem, or can it be controlled?
12. Are the costs acceptable?

CONSTRUCTION COSTS

Costs for LS and JP projects are comparable to those for other bank

stabilization techniques. Following are Year 2001 cost ranges for LS and JP projects based on the authors' experiences. These include profit margins and contingency factors on contractor bid projects.

The LS costs range from \$3 to \$10 each, while the JP costs range from \$6 to \$15 each. These prices include harvesting, transportation, handling, fabrication, and storage of the live cut branch materials. Costs for other system elements (e.g. riprap) and bank reshaping are not included. Costs may vary with access, availability of live material, time of year and prevailing labor rates. Fabrication of the LS or JP is simple and is performed either just prior to installation in moist climates and a week prior in dry areas. In dry areas, soaking the living stakes for a week in water improves survival. Both LS and JP structures may be fabricated in custom length for special needs. Installation is also relatively easy, as large equipment is not required except to slope back the bank. Fabrication and installation costs are usually low.

SITE CONSIDERATIONS

A site suited to LS or JP treatments requires a hydrologic regime that 1) keeps the invert of the stake wet during most of the growing season where the establishment of woody plants are desirable; 2) allows the roots to reach the water table or vadose zone during most of the growing season; and 3) sustains flows sufficient to keep woody plants growing well but not large and long-duration of flows so as to exceed the plant's flood tolerance. Given these requirements, streams best suited have perennial flows and are small to moderate in size, although the authors have successfully applied these treatments on a wide range of systems. Some variation in water surface elevation associated with baseflow is acceptable. However, the roots must have access to water.

The second most important factor in site selection is choosing a site that is not subject to massive amounts of sediment movement that could smother plants establishing on the bank. After they become

established, however, LS and JPs are effective in trapping soils from stream flows. They also establish conditions for subsequent colonization or planting, most often within the captured sediment. When LS's are used along a stream system, installation should follow the stabilization of the upper bank face using an appropriate erosion control fabric.

A site suited to LS or JP treatments must have adequate soil (growing medium) available to allow for root penetration. Lean clays and highly compacted soils inhibit root growth and generally result in poor success. Soil pH should be in the range of 6–8, and the soils should have sufficient nutrients or be augmented with a slow release fertilizer. Inoculation of the soils with mycorrhizae to stimulate root growth is often helpful.

Other important considerations in site selections are shade conditions, type of substrate in which they will be placed, and their relation to the channel thalweg. Most plants that are desired for establishment are shade intolerant and require some sunlight. As a general rule, moderate sunlight exposure should exist for LS and JP structures. There are exceptions where shade-tolerant plants (e.g. viburnum) can be used, but success is often poor. Consult the Natural Resources Conservation Service offices for information on local plants suitable for the area of interest.

A cobble substrate or one laden with interspersed rock can require special equipment or materials to achieve penetration. LS's and JP's may be installed 1.5 to 4 ft deep and diameters in the 1- to 2-in. range are typically most successful, so driving these stakes into a hard substrate can be problematic. For highly erodible bank materials, LS should be protected with a stone toe buttress to prevent scour and undercutting and an erosion control material to prevent surficial erosion.

DESIGN

Primary Design Considerations

Depth of erosion must be in the range of 1 to 3 in. for the LS system to be an effective immediate erosion control method when used with erosion control fabric. Elevation of the LS and JP systems must be suited to the vegetation for which they provide substrate. In general, the LS or JP must be at an elevation that permits absorption of water from groundwater seepage from the bank to prevent desiccation of the vegetation. However, it must not be placed so low as to inundate the vegetation beyond its flood tolerance. When willow branches or other woody plants are used in LS or JP constructions, their basal ends are inserted well into a moist zone within the bank (Figures 2 and 3). There is no requirement for periodic wetting. In these cases, LS's are intended primarily to provide sediment and erosion control after the woody vegetation has become established.

The LS's or JPs are typically installed in a random pattern or in rows and spaced apart according to slope and soil conditions illustrated in Tables 1 and 2. On moist seeping banks, more LS's may be used to assist in moisture depletion.

Table 1. Live Stake Spacing		
Slope Steepness ²	Spacing – feet O.C. ¹	
	Soils	
	Cohesive	Non-Cohesive
1:1	2 to 3	N/A
2:1	3 to 4	2 to 3
3:1 or flatter	4 to 6	3 to 5
¹ O.C. = On Center ² Assumes stable slope Note: Recommended to be used with an erosion control fabric		

Table 2. Joint Planting Spacing		
Slope Steepness ²	Spacing – Feet O.C. ¹	
	Soils	
	Cohesive	Non-Cohesive
1.5:1	N/A	N/A
2:1	1.5 to 3	1.5 to 2
3:1 or flatter	3 to 5	2 to 4

¹ O.C. = On Center
² Assumes stable slope
Note: All are recommended to be used with loose dumped riprap or evenly placed no deeper than 18" with filter fabric or filter stone in non-cohesive soils.

Only limited data have been collected for shear or velocity tolerances of LS and JP structures. Available data come largely from empirical information collected from constructed projects (Tables 3 and 4). Designers should exercise caution in considering limiting velocity or shear stress criteria. Failure of LS or JP structures can be attributed to several mechanisms, notably flanking, and undercutting.

Table 3. Live Stakes in Bare Soil Before Established		
Soils	Velocity, ft/sec	Shear, lb/ft
Silts	.05	.001
Sands	.5	.01
Large Gravel	2	.5
Large Cobble	4	2
Firm Loam	2.5	.08
Stiff Clays	3 - 4	.25
12" Rounded Riprap	6	4

Table 4. Live Stakes with Erosion Control Fabrics Prior to and After Establishment		
Fabric	Velocity, ft/sec	Shear, lb/ft
Jute		
Before Est.	1 – 2.5	.45
After Est.	3 – 7	2.1 – 3.1
Woven Coir – 700gm wt.		
Before Est.	3 – 5	2 – 2.5
After Est.	3 - 10	2.1 – 3.1

Success for both LS's and JP's requires that protection be provided against undercutting and flanking of the treatment. For toe and flank protection, rock protection should be designed for velocities and shear stresses exceeding allowable limits for the soils and rock underlying and within the LS or JP. Fischelich (2001) presents these limits. Angular rock is recommended and should be sized in accordance with the U.S. Army Corps of Engineers (1994) specifications depending on anticipated velocities and shear stress.

Flank protection can also be aided by keying the ends of the LS or JP systems into the banks at both ends and protecting the flanks with a rock protection. Key ends well into the bank with rock on the upstream side, which is also keyed into the bank. For banks susceptible to significant erosion, keys or refusals extend farther into the bank.

Table 5. Threshold Conditions					
Class Name	D _s (IN)	φ (DEG)	τ _c	τ _c (LB/SF)	V _c (FT/S)
Boulder					
Very large	>80	42	0.054	37.4	25
Large	>40	42	0.054	18.7	19
Medium	>20	42	0.054	9.3	14
Small	>10	42	0.054	4.7	10
Cobble					
Large	>5	42	0.054	2.3	7
Small	>2.5	41	0.052	1.1	5
Gravel					
Very coarse	>1.25	40	0.050	0.54	3
Coarse	>0.63	38	0.047	0.25	2.5

Other Design Considerations

Other design considerations, including the length of bank and face width being eroded, will determine the length of the treatment needed.

Eroded banks are not always conducive to immediate LS or JP installation and typically require reshaping or filling treatment to accommodate the use of LS or JP installation. If fill is required, rock fill mixed with other substrate suitable for plant growth

will be needed for LS. Rock alone is often used to prevent undercutting. Fill will need to be calculated based on cross-sectional area of the bank times the length of reach. Size of rock and appropriate gradation should be determined from U.S. Army Corps of Engineers (1994).

FABRICATION

LS's and JP's are fabricated using fresh, live cut branch material that roots easily from cuttings, typically harvested from a natural stand within 40 miles of the project site. The materials should be dormant and free of splits, rot, disease, and insect infestation. The rootable material that is to make up the stakes should be selected with consideration given to the type that exists on adjacent areas. Native naturally growing plants such as willow or shrub dogwood species work well and are usually available.

Material should be harvested from plants that are at least 2 years old. Harvesting of live material should leave at least one third of the parent plant intact. Live cut branches should be from 0.5 to 1.5 in. in diameter, 1.5 to 3 ft in length for LS's, and 0.75 to 2 in. in diameter and 2.5 to 3.5 ft in length for JPs. Cleanly remove all side branches. The bottom or basal end of the cuttings should be cleanly cut at an angle and the top end should be cut square (flat).

The LS's are prepared in bundles of 10 to 25 with the growing tips oriented in the same direction. Age, size, and species should be mixed when bundling to reflect the desired distribution of installed plants. Harvested material should not be allowed to dry. If it is necessary to harvest material significantly before installation, the stakes should be stored in wet burlap at approximately 33 to 40 deg F. Alternatively, one third of the basal end could be stored in cold water.

CONSTRUCTION

The primary considerations concerning construction with an LS and JP are bank preparation, soil types, moisture availability, and physical handling and installation of live stakes. Stakes should be soaked for a

minimum of 24 hr in cool, aerated water prior to installation. Rocks or burlap sacks can be used to anchor the material in the stream to prevent it from floating away. Optimum time for soaking is 5 to 7 days but they can also be planted the same day as harvested if they are watered.

Installing LS's or JPs may be as simple as tamping the live cutting directly into the ground with a dead blow hammer. If the ground is hard or rocky, it may require a punch bar or stake to create a pilot hole. The hole should be two-thirds to three-fourths the length of the stake and of approximately the same diameter. If the area is dry, it may be advisable to water the hole prior to installing the stake. Stakes must be installed with the basal end down. Stakes that are split during installation should be removed and replaced. Care should be taken not to damage the cambium layer of the stakes.

At least two buds or bud scars should be present above the ground, so an installed LS generally has 3 to 6 in. left exposed above ground. Greater lengths of exposed stakes increase desiccation and reduce survival. Good soil-to-stem contact is required for proper rooting, so it may be necessary to add soil slurry to pilot holes. The ground around the LS is typically foot tamped to ensure good soil contact. JPs may be installed leaving a few inches above the riprap rock, but are generally cut flush with the top of the riprap. When live stakes are installed into erosion control fabric, the woven threads must be spread apart or a small hole cut/punched into the fabric. The hole should be as small as possible to preserve the fullest bank protection available from the erosion control fabric.

Time of Year

LS or JP need to be harvested in the dormant season for the best results and for the most cost-effective project. They are generally best installed during the dormant season as well, but can be installed any time of the year if the cuttings are properly stored (at 30–40 deg F, in a low moisture environment, and with no direct sunlight

exposure). Installation into frozen or heavily frosted soils is difficult, at best, so late fall and early spring are the preferred installation times throughout most of the United States.

OPERATION AND MAINTENANCE

Operation and maintenance requirements of any soil bioengineering treatment will vary depending on the stream system and its associated parameters, such as velocity, flood frequency, flood stage, timing, and future planned use. In any case, be prepared, at least early in the project life, to repair or augment the systems until the vegetation becomes well established. Minimally, inspection should occur after each of the first few floods and/or at least twice a year the first year and once a year thereafter, preferably after the predominant flood season.

Immediately repair observed undercutting and flanking of the treatment and any other substantial scour evidence. Examine the live cuttings in the LS or JP for adequate survival and growth and absence of disease, insect, or other animal damage (e.g., grazing, trampling, digging, eating, and cutting). Successful plants will grow vigorously and spread their roots into the surrounding substrate.

If animal or human trampling damage is evident or the plants are being removed or eaten by waterfowl or beavers, preventative measures such as exclosures may be required. Such exclosures, especially for woody plants, may only need to be used until the vegetation is well established (1 to 3 years).

Assuming the LS and/or JP remains in place and vegetation becomes established through the development of growth from the live cutting or through plant development from natural invasion, maintenance becomes less over time.

Fish and aquatic invertebrate sampling is always recommended both before installation to gather base information and

after the installation has become established (1 to 3 years), to determine habitat improvement effectiveness.

APPLICABILITY AND LIMITATIONS

Techniques described in this technical note are generally applicable where primary objectives for streams include habitat diversity, erosion control, water quality improvement, and aesthetics, including a diversity of riparian plants along the streambank. LS or JP systems are expected to establish on a wide range of streams having fairly constant and consistent base flows as well as ephemeral stream systems. However, vegetation may tend to dry out and die in extreme conditions and where installations are not deep enough to allow roots to reach adequate moisture. This may be especially true for JPs. Streams should not have excessive sediment loads that may completely cover and smother the establishing LS or JP. Some caution is also needed when selecting the species for LS or JP.

Exercise caution in using JP or LS without a rock protection or other hard material when stream velocities at the bank exceed critical thresholds for underlying soils.

Trampling and grazing of LS can be detrimental from a living perspective. Use may be limited in areas where cattle grazing is not restricted. Note that due to safety, live stakes are not recommended over the bank in high traffic areas where people may trip and fall on them.

Consider the time of year when installing LS's or JPs as well as water elevation. Consider consequences of failure if an LS or JP is flanked and washed downstream and if the failure is likely to create hazards that otherwise would not occur (e.g., trapping debris and causing undesired local scour, current deflection, and damming).

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REFERENCES

Fischenich, C. 2001. *Stability thresholds for stream restoration materials*. EMRRP Technical Notes Collection. ERDC TN-EMRRP-SR-29. Vicksburg, MS: U.S. Army Engineer Research and Development Center. www.wes.army.mil/el/emrrp.

U.S. Army Corps of Engineers. 1994. *Hydraulic design of flood control channels*. Engineer Manual 1110-2-1601, Change 1, 30 June 1994. Washington, DC.